TOWARD A SUSTAINABLE NEIGHBORHOOD: EXAMINING THE IMPACT OF MIXED-USED DEVELOPMENT ON NEIGHBORHOOD ENERGY CONSUMPTION

An Option Paper

by

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LIST OF SYMBOLS AND ABBREVIATIONS

VMT	Vehicle Miles Travel
MXD	Mixed Used Development
TOD	Transit Oriented Development
DOE	Department of Energy
TAZ	Traffic Analysis Zones
ABM	Activity Based Model
ARC	Atlanta Regional Commission
CT-RAMP	Coordinated Travel Regional Activity-Based Modeling Platform
EV	Electrical Vehicle
EPA	Environmental Protection Agency
MUTGM	Mixed Used Trip Generation Model
ITE	Institute of Transportation Engineers
MPG	Miles Per Gallon
PECAS	Production Exchange Consumption Allocation System

SUMMARY

The population in urban area is expected to increase more than 12% during the next 30 years. The Transit Oriented Development (TOD) is a fast-growing trend in creating a sustainable community in urban areas. TOD goes beyond a dense development strategy to oppose the sprawl development, and suggests a compact development around transit system, with a pedestrian-friendly and mixed-used environment. TOD proves to bring many benefits to residents such as providing a low-stress atmosphere with much lower automobile dependency for the residents, reduction in carbon footprint, stimulation of the local economy, and higher accessibility. The impact of TOD on building stock and transportation can result in change in energy consumption per capita compared with a regular urban development strategy. In this study, I assess the impact of TOD on energy consumption in two main sectors: residential (buildings) and transportation in the city of Atlanta. The scope of study consists of three neighborhoods that are selected from three different socio-economic levels within the boundary of the Atlanta Metropolitan area. This study compares the energy consumption in both residential (building) and transportation sectors, before and after the TOD for each of the selected areas. The result of this study can help city planners, investors, and policy makers to develop a better strategy for a sustainable urban development via TOD, while aiming any specific neighborhood with strategies tailored to socio-economic characteristics of the target area.

CHAPTER 1. INTRODUCTION

The energy consumption in the world shows a positive trend during the past decades[1]. The source for the world total consumed energy is mainly fossil fuel (more than 65%)[2]. The negative impact of burning fossil fuels on the environment, forced countries to implement more restricted policies and regulation to decrease the Greenhouse Gas emissions, via the improvement of overall efficiency in both consumption and production sides, while introducing renewable energy sources that not only impose less harm to the environment, but also economically feasible to implement across the globe[3].

In the United State, residential and commercial sectors have a share of more than 11% for the total energy consumption, while the transportation sector consumes more than 28% of the total energy generated in one year[4]. The improve of efficiency in the energy consumption sectors, even at a low percentage, can result in a significant energy saving and considerable positive impact in the fight against the global warming and climate change issues. Moreover, a sustainable growth in any continental requires a steady and reliable energy service over time. One of the goals in the "2030 Agenda for Sustainable Development" report by the UN is the access to "affordable, reliable, sustainable, and modern energy" for all. In another report by the UN, projects the population in Urban area will increase from 54% in 2014 of total world population to 66% in 2050[5]. Such a steep growth rate of urban population will increase the demand for energy in cities. Furthermore,

[1] "Statistical Review of World Energy | Energy Economics | BP Global."
[2] "Publication: World Energy Outlook 2016 - Excerpt - Water-Energy Nexus."
[3] "Learning About Renewable Energy | NREL."
[4] "Annual Energy Review - Energy Information Administration."

the dependency of residents to their personal vehicle for the everyday commute adds up the energy consumption rate in urban areas. Such an increase can be magnified, if we have a sprawl development which would result in an increase in the total Vehicle Miles Travel (VMT) within the developing areas[6].

Transit Oriented Development (TOD) is a promising development method in urban areas, where some compact, mixed-used neighborhoods is being realized around existing or new transit station[7]. Mixed-Used Development (MXD) is defined as consisting of two or more land uses between which trips can be made by using local streets (including walking trips) without having to use major streets[8].

In this study, I investigate the impact of TOD on the overall energy consumption of neighborhoods. The energy consumption is calculated for two end-use sectors: residential buildings and transportation. Three neighborhoods in the Atlanta metropolitan area are selected and the aggregated energy consumption is calculated for before and after the implementation of TOD in each neighborhood. The three neighborhoods are selected from the three different socio-economic levels and the impact of TOD is examined for each neighborhood, separately. The rest of this paper is organized as follows: the next chapter presents a literature review for three subjects: TOD and its impact on transportation, Energy Consumption Calculation in urban areas for the two end-use sectors: transportation and residential (buildings). Chapter 2 presents the methodology I use for calculating the impact of TOD on transportation and building stock, along with the energy consumption

[6] Jared Rodriguez, "Special Section."
[7] De Vos, Van Acker, and Witlox, "The Influence of Attitudes on Transit-Oriented Development."
[8] Gulden, Goates, and Ewing, "Mixed-Use Development Trip Generation Model."

calculation for the both mentioned end-use sectors. In the third chapter the case study of Atlanta is presented and the result of the energy consumption for each of the selected neighborhoods is shown and explained in detail. The last chapter discusses about the result and conclude the study and its finding.

CHAPTER 2. LITERATURE REVIEW

In this section, I provide a literature review of the main themes of this paper: the TOD and its impact on the energy consumption in the urban areas, including the impact of urban form, MXD, and the overall impact of TOD on the transportation. Furthermore, I comprehensive survey over the existing methods for calculating the energy consumption in residential and transportation sectors. This section provides a review of the research findings from the previous studies in three subsections: • TOD, • urban form and its impact on energy consumption, and • building and transportation energy consumption.

2.1 Transit Oriented Development (TOD)

TOD mainly refers to a dense, mixed used, and walkable development within walking distance to transit stops. However, there is not a clear universal definition for TOD and it may be hard to define measurements to assess TOD and its goal in different areas and regions (Cervero 2004). Federal Transit Authority defines the TOD as compact, mixed used, and walkable development near a transit facility that can promote economic development, creates sustainable communities, boots transit ridership, and can provide benefits to both public and public sectors (FTA 2000). Transit Oriented Development concept shaped around the idea of providing an alternative to the growing road traffic congestion, improvement of accessibility and public safety, increase ridership, reduce rates of Vehicle Miles Travel and pollution, conserve land use and open spaces, improve economic development, and brings more affordable housing for the residents in the neighborhood [9]. The TOD has gone through several phases in the united states, where the first generation of TOD only focused on advocating the concept, and at the current phase, it reaches a point that the researcher can measure and understand the travel outcome of TOD[10][11].

The studies on TOD shows the ridership of transit systems increase in the TOD zones, whereas the transit ridership experienced a decline in areas surrounding the TOD zones in urban areas[12]. The same study shows that the households that are living within the TOD zones have twice the likelihood of not owning a car. However, to gain the benefits of TOD, it is important for the households to have access to the high quality transit system.

The study of the travel characteristics of the people who live in a TOD zone reveals they use transit system two to five times more than the other commuters in the study region, and the transit mode share has a large variation from 5% to 50%[13]. The travel time is the reason for such a high range for transit mode. If the transit system connects more job centers, educational opportunities, cultural facilities to the residential communities, we can have a higher ridership. Hence, the location of TOD zones and the accessibility rate the transit system can provide to its riders are the most important factors in selecting the TOD zones.

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[9] De Vos, Van Acker, and Witlox, "The Influence of Attitudes on Transit-Oriented Development"; Cervero and Sullivan, "Green TODs"; "Transit Oriented Development | Atlanta Regional Commission."

[10] Ratner and Goetz, "The Reshaping of Land Use and Urban Form in Denver through Transit-Oriented Development."

[11] National Academies of Sciences, *Effects of TOD on Housing, Parking, and Travel*.

[12] Cervero, "Transit-Oriented Development's Ridership Bonus."

[13] "Travel Characteristics of Transit-Oriented Development in California."

The Mixed-used development in TODs makes the transit system service suitable for a variety of trip purposes throughout the day. However, the employment access is the primary consideration of the TOD residents[14]. In this case, the mixed-use development and urban design treatment (such as walkways) are the amenity and the additional value that can attract the residents and visitors. Local land use mix can influence the TOD prospective residents choose of neighborhood among the TOD zones, in addition to make it more desirable location to travel.

2.2 Urban Form and its Impact on Energy Consumption

The urban form and its impact on the energy consumption has been the subject of many studies in the past[15][16]. However, there has been a long debate on the significance of the impact of urban form on the energy use. A question that acts as a focal point in those is: Is it possible to explain the building energy as a function of urban form, and to what is the share of the other factors such as human behavior, building design and energy system efficiency in that manner? (Ko et al., 2012; Dimitrova, 2014; Bakar and Cheen, 2013; Rosales, 2011; Guedes et al. 2009; Ratti et al 2005; Mitchell, 2005). In the US, buildings are the largest source of energy consumption, accounting for 41% of the total annual energy consumption (EIA, 2015). Residential and commercial sectors respectfully consume 22% and 19% of the total energy used (EIA, 2011). In the cities that people use more public transit system than personal vehicle for the commutes, the building sector accounts for a higher percentage in total annual energy consumption (Steemers, 2003). A study by

[14] "Transit and Job Accessibility: An Empirical Study of Access to Competitive Clusters and Regional Growth Strategies for Enhancing Transit Accessibility."
[15] Williams and Jenks, *Achieving Sustainable Urban Form*.
[16] Banister, Watson, and Wood, "Sustainable Cities."

Mitchel (2005) on urban energy use in London, a dense city where the public transportation encounters a large proportion of everyday commutes, the author shows the ratio of energy used in buildings compare to transportation has the ratio of 2.2. It is a proven fact that the increase in the efficiency of appliances, improve the building insulation, changing people's behavior, and other non-spatial options can decrease the energy consumption in urban areas. However, the impact of urban form is large enough that without considering it as one of the factors, it is not possible to achieve a sustainable energy system for urban and sub-urban areas. The impact of the energy crisis in the 1970s, ignites the start of several research, to study the impact of the urban form, on the building and transportation energy use. Simulation studies have been conducted with the focus on the effect of a single or range of variables (such as: building size, windows to floor ratio, shading effect of tree canopy, wind flow, and …) (Tahmasebi et al. 2011). A study by Ewing and Rong (2008) analysis the impact of urban form (housing size, housing type, and density) on building energy consumption, using a multivariate statistical analysis method. Some of the criticism of that paper are: ignoring the impact of other factors such as energy pricing in the calculation, insufficient evidence on legitimate link between spatial variables and building energy consumption, and finally the necessity of using complex statistical analysis instead of simulation method that has the capability of controlling other variables (Randolph, 2008; Staley, 2008). Building simulation tools can test a variety of variables, including housing size, type, etc. to estimate energy use for individual building. Currently there are several available tools that can be used to assess the energy use for individual building. Some of the such simulation tools are: Energy10, Ecotect, eQuest, Energy Plus, and DOE-2. These tools have been used to estimate the energy use and are validated by some studies (such as

Meldem and Winkelmann 1998). It is not possible to model energy individual building, when we aim to assess the energy consumption at an urban scale. The empirical approach has been used to estimate the energy consumption of a neighborhood. Researchers have been using statistical analysis methods with the Residential Energy Consumption Survey (RECS) as an input along with other variables to assess energy uses at urban level since 1970s. Hirst et al. (1982) use the empirical approach, to show the floor area is an important deterministic factor in heating energy consumption. The adjustment of other variables influencing the residential energy consumption is one of the limitation of this method (Owens 1986). In another study, Holden and Norland (2005) argue the built year is a significant factor in building energy consumption. The impact of the density on building energy consumption also was the subject of several studies (Ali-Toudert and Mayer 2006; Arnfield 1990; Givoni 1998; Cheng et al. 2006; Hough 1995). The assessment of the density and energy consumption shows in general the increase in density would increase the energy consumption. However, the energy use per capital would decrease when the density increases.

2.3 Estimate Energy Consumption in Urban areas - Methods

There are two main approaches for estimating the energy consumption of a single or group of neighborhoods[17][18]: top-down and bottom-up, which are briefly described in this section.

[17] Swan and Ugursal, "Modeling of End-Use Energy Consumption in the Residential Sector."
[18] Heiple and Sailor, "Using Building Energy Simulation and Geospatial Modeling Techniques to Determine High Resolution Building Sector Energy Consumption Profiles."

The top-down method relies on extensive historical data (3 to 5 years of hourly data). The spatial resolution of available data can be as fine as individual city, but generally it is at state, regional, or even national scale. In this method, researcher derive a finer resolution dataset, using a desegregated energy consumption at higher spatial levels, and transform it into a neighborhood scale level based on diurnally varying population density[19]. The difficulty in obtaining the required detailed data often result in simplification, in spatial variation and this approach is applicable for cities with available data at a larger scale.

The bottom-up method, in contrast with the top-down method, develops the energy consumption data at building level scale and aggregate the result to the desirable higher scale level. This method is more popular among scholars that aim to examine the energy consumption of an individual building and the impact of building design and technology on the total energy consumption of the building. Moreover, this method is suitable for cases where the electricity consumption and other energy sources are needed to evaluate separately. The US Department of Energy (US DOE) provides a nationwide residential and commercial building stock information that makes it possible to use them as a start point for the energy consumption estimation using the bottom-up approach. However, due to limited sample size, the result may not be as accurate as calculating the modeling the energy consumption of individual buildings.

There is a third estimation approach that can be categorized as a hybrid bottom-up approach. In this method, the result from the statistical sampling dataset generates an energy consumption characteristics of the building stock within the scope of the study, and

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[19] Sailor and Lu, "A Top-down Methodology for Developing Diurnal and Seasonal Anthropogenic Heating Profiles for Urban Areas."

the data are then linked with a detailed representation of the spatial distribution of building types in the neighborhood[20][21][22].

In the next chapter the methodology that is being used in this study to examine the energy consumption in residential and transportation sector, along with the impact of TOD is explained in detail.

[20] "Impact of Anthropogenic Heat on Urban Climate in Tokyo."
[21] "Impacts of City-Block-Scale Countermeasures against Urban Heat-Island Phenomena upon a Building's Energy-Consumption for Air-Conditioning."
[22] Heiple and Sailor, "Using Building Energy Simulation and Geospatial Modeling Techniques to Determine High Resolution Building Sector Energy Consumption Profiles."

CHAPTER 3. METHODOLOGY

This chapter, first presents the methodology that is being used to examine the energy consumption in two sectors of residential and transportation. The last part of this chapter, explains the method for examining the impact of TOD on the building stock and transportation.

3.1 Estimate Energy Consumption in residential sector

The energy consumption at residential sector, mainly related to secondary groups of end-use such as heating and cooling, domestic hot water, appliances, and lighting under the main residential sector. The energy use in the mentioned secondary end-use groups highly dependent to the climate, housing units, home appliances, temperature control system, and household behaviors[23]. In this study, considering the available data sources for both energy consumption and neighborhood level characteristics, I picked the bottom-up energy estimation method, where a combination of statistical and engineering method is being used to examine the energy consumption at the three preselected neighborhoods. Among the three statistical techniques for evaluating and estimating the energy consumption (regression, conditional demand analysis, and neural network), I picked the regression method. In the regression method, the regression analysis is used to determine the coefficient of the model corresponding to the input parameters. The combination of the parameters of the dwelling units within the scope of the study are considered as the dependent parameters. The model is evaluated by its goodness of fit, where the input

[23] Swan and Ugursal, "Modeling of End-Use Energy Consumption in the Residential Sector."

parameters with negligible effect are removed as well as those parameters that have intercorrelation (determined by the stepwise regression method).

To select the parameters in the regression, I first identify the related factors in two major categories: behavioral and contextual. The life style and consumption behavior determines the behavioral factors, such as the median household income[24]. The contextual factors relate to the effect of physical attribute of buildings. The size of the housing units and housing types are the example of physical factors affecting the energy consumption in the residential sector[25].

Table 1 – independent parameters for the residential energy consumption.

Behavioral	Physical (contextual)
Median Household Income	Average Household Area (Sq.Ft.)
Location	Building Type
Average Household Size	Building Age
Urban vs Rural	Climate

The interdependent factors are used in running the regression on the filtered data set from the Residential Energy Consumption Survey (ver. 2013). The result of the regression

[24] Lutzenhiser, "A Cultural Model of Household Energy Consumption."
[25] O'Neill and Chen, "Demographic Determinants of Household Energy Use in the United States."

is used to estimate the energy consumption in the residential sector for each neighborhood separately.

3.2 Estimate Energy Consumption in transportation sector

The use of fuel for transportation purposes predominantly related to the VMT, the most commonly cited measure of passenger transportation in the US[26]. The impact of various factors on VMT has been the subject of many studies in the past[27][28]. There are two major transportation modeling approaches that can be used to generate the VMT: 1- four step model, and 2- Activity Based Model (ABM).

In a recent effort by Atlanta Regional Commission, the travel demand model via four step modeling technique is replaced with the behavioral model (ABM). The ARC's ABM is based on the Coordinated Travel Regional Activity-Based Modeling Platform (CT-RAMP) which addresses both household-level and person-level travel choices including intra-household interactions between household members[29][30]. The Activity Based Model (ABM) of the ARC forecasts typical weekday trips along with the travel distance for each individual trip for different trip modes. The result of the ABM is a large CSV file (4.5 GB) containing more than 19 million individual trips within the Atlanta Metropolitan Area. The preselected TAZ zones for each neighbourhood are used to extract the individual trips in each neighbourhood and the aggregated distance is calculated as the total daily VMT. The energy consumption in the transportation sector, then estimated under two scenarios: 100%

[26] Rentziou, Gkritza, and Souleyrette, "VMT, Energy Consumption, and GHG Emissions Forecasting for Passenger Transportation."
[27] Polzin, Chu, and Toole-Holt, "Forecasts of Future Vehicle Miles of Travel in the United States."
[28] Brownstone and Golob, "The Impact of Residential Density on Vehicle Usage and Energy Consumption."
[29] "Transportation Access and Mobility | Atlanta Regional Commission."
[30] "Modeling."

combustion engine vehicle, and 2- a 100% adoption of Electrical Vehicle (EV). The energy consumption then calculated based on the national average energy consumption of vehicles for each category. In this study the energy consumption in the transportation sector is limited to car mode.

The energy consumption is then estimated by using the result total VMT from the ABM model and Miles Per Gallon (MPG) data from National Household Travel Survey (NHTS). Based on the assumption the proportion of vehivle type in NHTS is a fraction of that type of vehicle within the entire vehicle inventory, the energy consumption in transportation sector is estimate by using the following formula:

$$Energy\ consumption\ in\ Transportation\ secotr = \sum_{i=1}^{n} VMT_i * Averge\ MPG_i$$

Where

VMT_i : $Comulative\ vehivle\ miles\ travel\ in\ each\ TAZs$

i : $TAZs\ surrounding\ each\ transit\ station$

3.3 Estimate the Impact of TOD on Building Stock and Transportation

The goal of this study is to examine the impact of the TOD on the energy consumption at the neighborhood level. The impact of TOD on the building stock and its consequence on the energy consumption in the residential sector is estimated based on the regression method that was developed in the previous section. The average household square footage is the main variable that will change in the calculation of energy consumption at residential sector. To estimate the impact of TOD on energy consumption in the transportation sector, we need to examine the impact of the TOD on the VMT. In this study, I use the "Mixed Used Trip Generation Model" (MUTGM) (v.4.0) that was developed by the Environmental Protection Agency (EPA) in corporation with Institute of Transportation Engineers (ITE). The model is tailored to estimate the trip-generation impacts of mixed-used development. EPA analyzed six metropolitan regions and merged the data from household travel surveys, and other sources to create a consistent land use and travel measures. This tool requires information about the development areas, including geographic, demographic, and land use characteristics. The input data are gathered from different sources, including US Census, Atlanta Regional Commission, and Zillow housing database.

CHAPTER 4. CASE STUDY –THREE NEIGHBORHOODS, ATLANTA, GA

4.1 Data Source

In this study, considering the wide range of factors influence the energy consumption in building and transportation sectors, a wide range of data sources is being used. The data sources in this study can be categorized into two main categories: 1-Input data for energy consumption calculation in the residential sector, and 2- Input data for energy consumption calculation in the transportation sector.

In this study the Residential Energy Consumption Survey (RECS) v.2009 was the main source reference for the building energy consumption calculation. RECS dataset is a national sample survey that collects the energy related information from households across the U.S Conducted by the U.S. Energy Information Administration. The survey sample size is 12,083 households which are selected randomly[31]. The survey sample is a representative of 113.6 million U.S. households. The 2009 version of RECS represents its 13th iteration and released in 2013. The first version of RECS was published in 1978. The RECS v.2009 unlike the previous versions contains a detailed side end-use consumption and expenditure data which are used to run the regression for estimating the energy consumption in the study areas in this study. RECS v2009 has 940 variables for each record. The variables that are selected from the list of independent variables in the RECS

[31] "Residential Energy Consumption Survey (RECS) - Data - U.S. Energy Information Administration (EIA)."

can be grouped into three categories: 1- location 2-household characteristics, and 3-physical characteristics. The location category contains variables that represent the geographical location of the household in the sample, such as the regional location. The household variables represent household specific characteristics of the sample such as the household median income. The physical characteristic factors are the representative of the buildings; where the households are living in, such as building square footage.

The American Community Survey (ACS), an ongoing survey conducted by the U.S. Census Bureau is used to gather the household information in the study areas[32]. ACS regularly collects information that was previously conducted by the long form format of the decennial census. The US Census Bureau aggregates the individual ACS responds and publishes the estimate at many geographic summary levels. Between these summary levels, there are statistical entities which at the finest grain the ACS data are available at the Census Block Group level. The ACS estimate is published in three formats: 1 year estimate, 3-year estimate, and 5-year estimate. The 5-year estimate is available for all areas down to the block group scale. The 5-years estimate summarize response received in a 5 years' consecutive years and is most suitable for the interest of long-term changes in small geographical scale. This study used the 5-year ACS estimate as the input for independent variables related to household characteristics for the study area to estimate the energy consumption in the residential sector. The most up-to-dated version of the ACS, at the time of this study, is the 2011-201that was issued in Sep.2016.

[32] Bureau, "ACS Information Guide."

To estimate the energy consumption in the transportation sector, this study used the results from the most up-to-dated Activity Based Model (ABM) developed by the Atlanta Regional Commotion (ARC). The ABM is the regional Travel Demand Model associated with the current Atlanta Regional Transportation Plan.(ARTP). The ABM addresses the household-level along with the personal-level travel choices. AS the result, it can reflect an impact of detailed demographic information, including household structure, aging, income changes, and other key attributes, in the travel modeling. The ABM is a part of a fully integrated transportation and land use model involving the Production Exchange Consumption Allocation System (PECAS) model. The PECAS is used to create small area forecasts from the regional control forecasts. This study used the result of the ABM model for the year 2015 as the initial Vehicle Miles Travel for the study areas.

4.2 Study Area

Atlanta is the capital of the U.S. state of Georgia. Three transit stations within the Atlanta Metropolitan area are selected as the study areas: Lindbergh Center Station, King Memorial Station, and Bankhead Station (Figure 1). In the Atlanta, the Metropolitan Atlanta Rapid Transit Authority (MARTA), is the principle public transport operator in the Atlanta Metropolitan area[33]. MARTA is the exclusive transit system operating in the Fulton, Clayton, and DeKalb counties, with both bus and rail transit systems. As of 2015, the average total daily ridership (bus and rail) of MARTA system was 432,900 passengers[34].

[33] "MARTA."
[34] "APTA Q4 2015 Ridership Report - 2015-q4-Ridership-APTA.pdf."

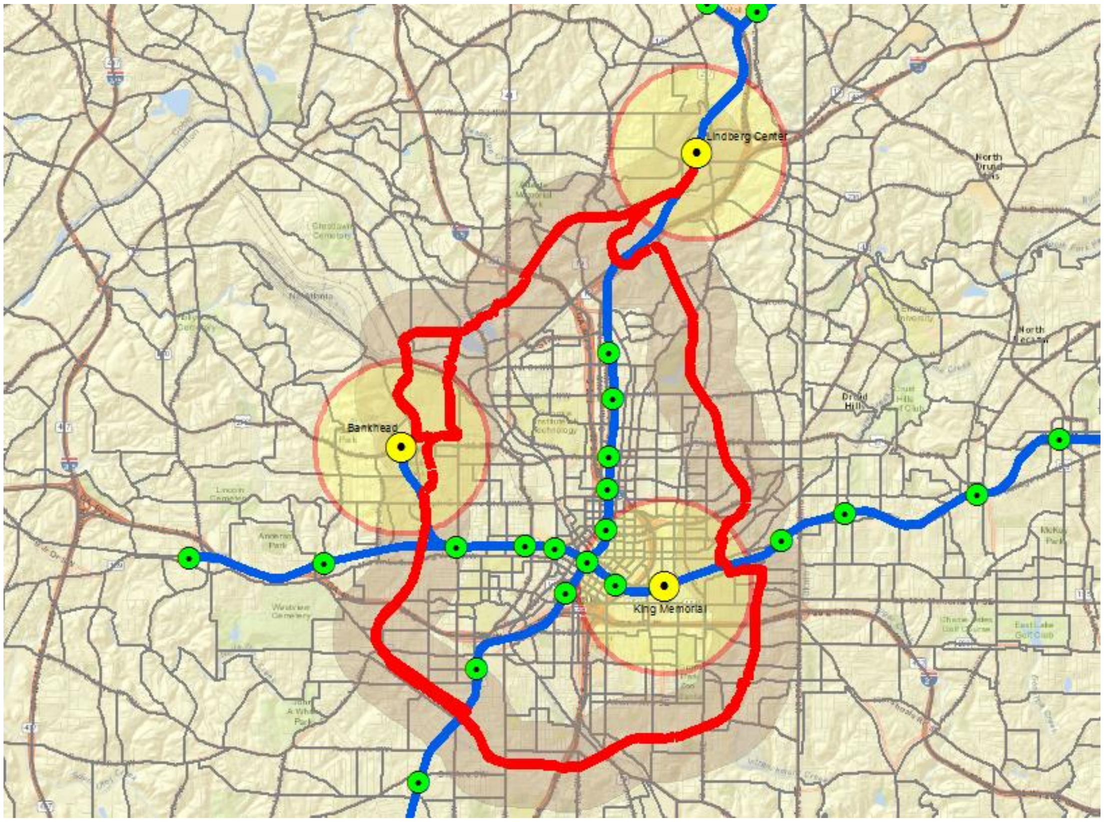

Figure 1 – MARTA Station in the Atlanta – Green and Yellow transit route. Atlanta Beltline Project (Red line). Selected station as the scope of this study are represented with yellow circle.

The three MARTA stations, subject to the scope of this study, are selected based on the two main criteria: 1- each station represents a different socio-economic characteristic for its surrounding neighborhood, and 2-each station has an approved TOD plan.

The neighborhoods in the Atlanta Metropolitan area can be divided into three socioeconomic levels, based on their income, education, poverty, and income level (Figure 2)[35]. Each MARTA station in this study represents one level of socioeconomic status in

35 "NQOLH SEC Index."

the Atlanta: Bankhead station represents the low socioeconomic condition, the King Memorial station is a representative of the Medium socioeconomic condition neighborhood, and Lindbergh Center station is the representative of high socioeconomic neighborhood condition in the Atlanta.

The second criteria for the selection of the transit station is the existence of an approved TOD plan for the surrounding neighborhood. There is an existing TOD plan for some of the MARTA stations[36][37]. MARTA developed and adopted a TOD over three goals: improve transit ridership, promote sustainability, and generate return on investment for MARTA system. The Atlanta TOD plan, suggests a high relative density, mixed use, pedestrian friendly, utilizes the parking spaces, and compact development around the transit station that can increase the return on investment of the MARTA transit system[38]. In the Atlanta, like most of the other regions in the US, the TOD plan considers similar goals for the entire metropolitan area, while the socioeconomic characteristics of the different areas within the boundary of the city, is not homogeneous.

[36] "MARTA."
[37] "coUrbanize - MARTA."
[38] "Transit Oriented Development | Atlanta Regional Commission."

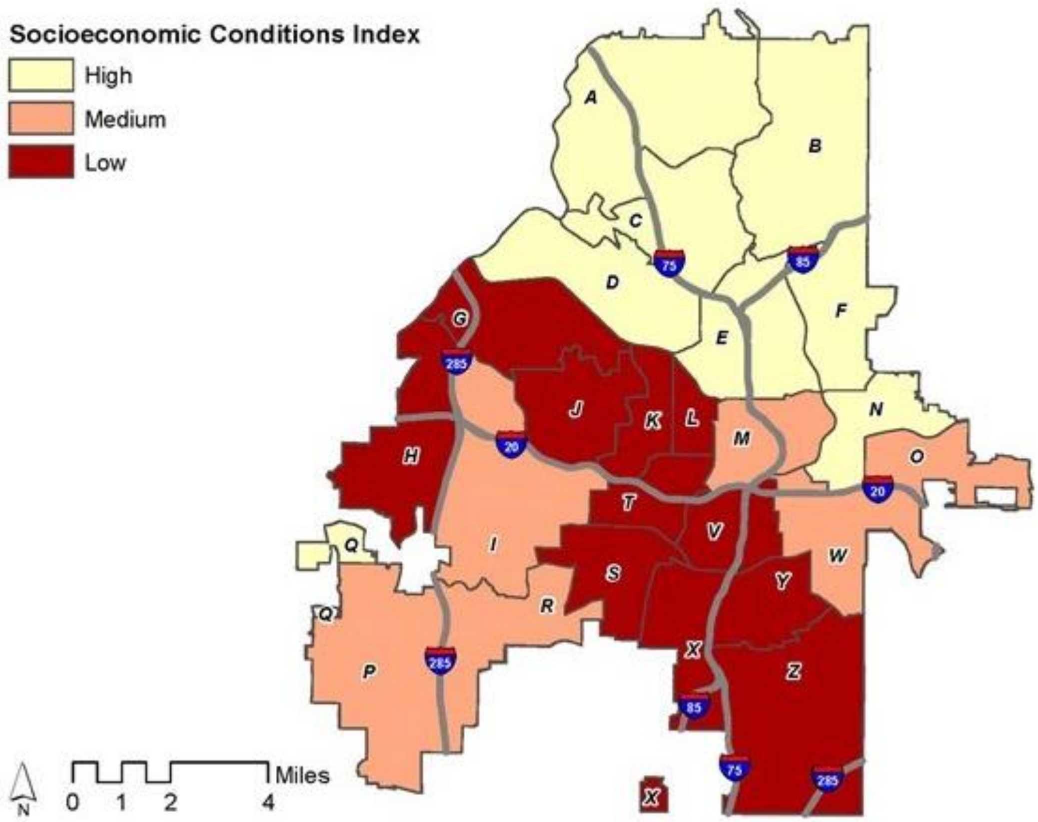

Figure 2– Atlanta Metropolitan Area: Three neighborhood categorization levels (Source cgis.gatech.edu/NQOLH/SEC_Index/)

In the following part, a brief description of each station is presented along with the TOD associated with the neighborhood surrounding the selected MARTA stations.

4.2.1 Lindbergh Center Station – TOD plan

The Lindbergh Center station is located between two upscale neighborhoods in the Atlanta: Midtown and Buckhead and is the last transfer point between the two northbound trains: Gold and Red lines. The Lindbergh Center station is the second busiest MARTA station, with average weekday boarding of 23,000 passengers[39]. The MARTA TOD area

[39] Lindbergh Center Station - Phase II TOD Master Plan.pdf."

surrounding the Lindbergh Center Station consists of four distinct subareas: 1- North Block, 2-Core Block, 3-Station Block, and 4-MARTA Annex (Figure 3).

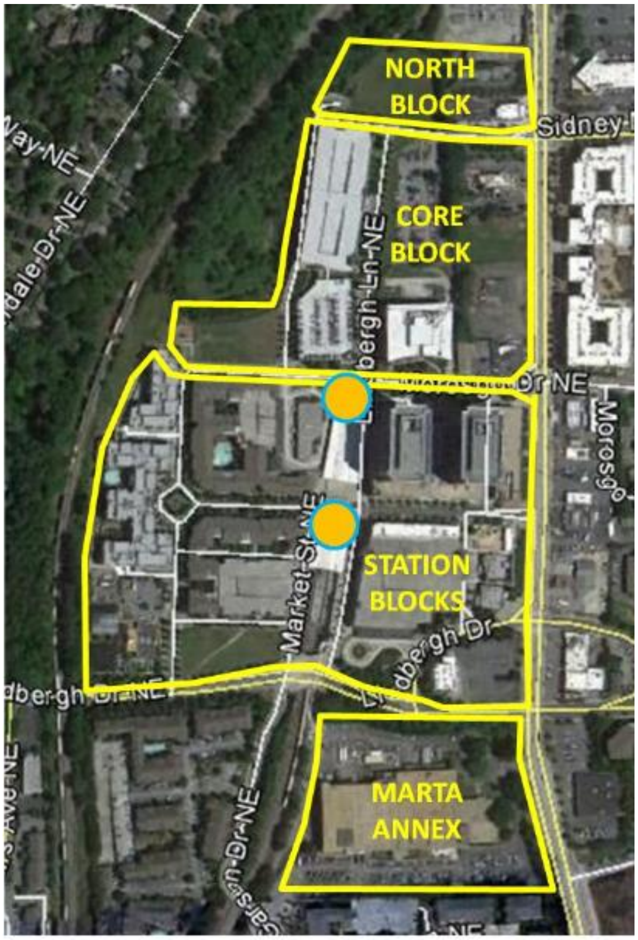

Figure 3 – Lindbergh Station – TOD plan Phase4 II (Source: Lindbergh Center Station - Phase II TOD Master Plan)

The demographic analysis of the areas surrounding the Lindbergh station shows there are currently and estimate of 3,311 households living within the ½ mile boundary around the Lindbergh Center Station. The projected population growth in the area surrounding the Lindbergh station shows a higher growth rate, compared with the City of Atlanta (Table 2).

Table 2 – Demographic Analysis – Lindbergh Station

Households	Lindbergh Center Station (1/2 Mile boundary)	City of Atlanta
2010 Census	2,750	185,484
2015 Estimate	3,311	204,281
2020 Projection	3,718	220,188
Growth rate	2.7%	1.3%

In 2015, MARTA undertook a phase II plan for the TOD in the Lindbergh Center Station, which makes it the first major TOD project of MARTA. The second phase of TOD plan covers a 47-acre mixed-used development surrounding the Lindbergh Center Station.

4.2.2 King Memorial Station – TOD plan

The King Memorial Station is a heavy rail transit station on Marta's two lines: Green and Blue. This station provides the rail service to major destinations including Midtown and Downtown of the Atlanta, as well as the Hartsfield-Jackson International Airport. There are currently 3,198 households living within a half miles of the King Memorial Station, with an average household size of 1.94 and Median Household income of $23k. King Memorial Station has a daily boarding rate of 1,941.

4.2.3 Bankhead Station – TOD plan

Like the two other selected MARTA stations, the Bankhead Station is a heavy rail transit station located in the geographical center of the Atlanta (city). The MARTA Green line passes the Bankhead Station. The demographic information about the area surrounding the Bankhead Station shows this station has the lowest number of households living within a ½ mile buffer with the sum of 1,381 households and a median household income of $26k. The Bankhead Station has the daily boarding rate of 1,952 which is at the similar range compare with the King Memorial Station.

4.3 Neighborhood Characteristics

This study limits its scope to the Traffic Analysis Zones that intersect with a half a mile buffer line across the three MARTA stations. To select the boundary for this study, we select the TAZ zones that intersected with a half mile buffer around each one of the selected MARTA stations. Figure 4 shows the selected TAZs based on the buffer zone for each MARATA station. The areas surrounding the Lindbergh Center station on average have the highest density among the three neighborhoods (Figure 5). The King Memorial Station has the second highest population density, while the area surrounding the Bankhead Station has the lowest population density. Although such a low population density makes of the areas surrounding the Bankhead station may makes this station less favorable for implementing a TOD plan, it also creates an opportunity for planners and developers to increasing the density.

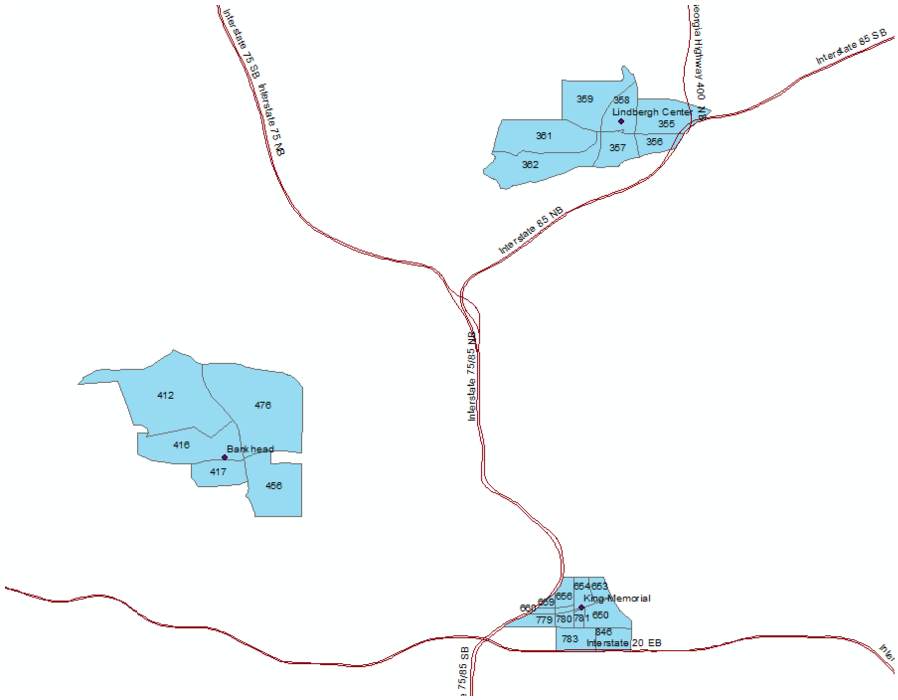

Figure 4 – Scope of the Study. TAZs surrounding the three MARTA stations.

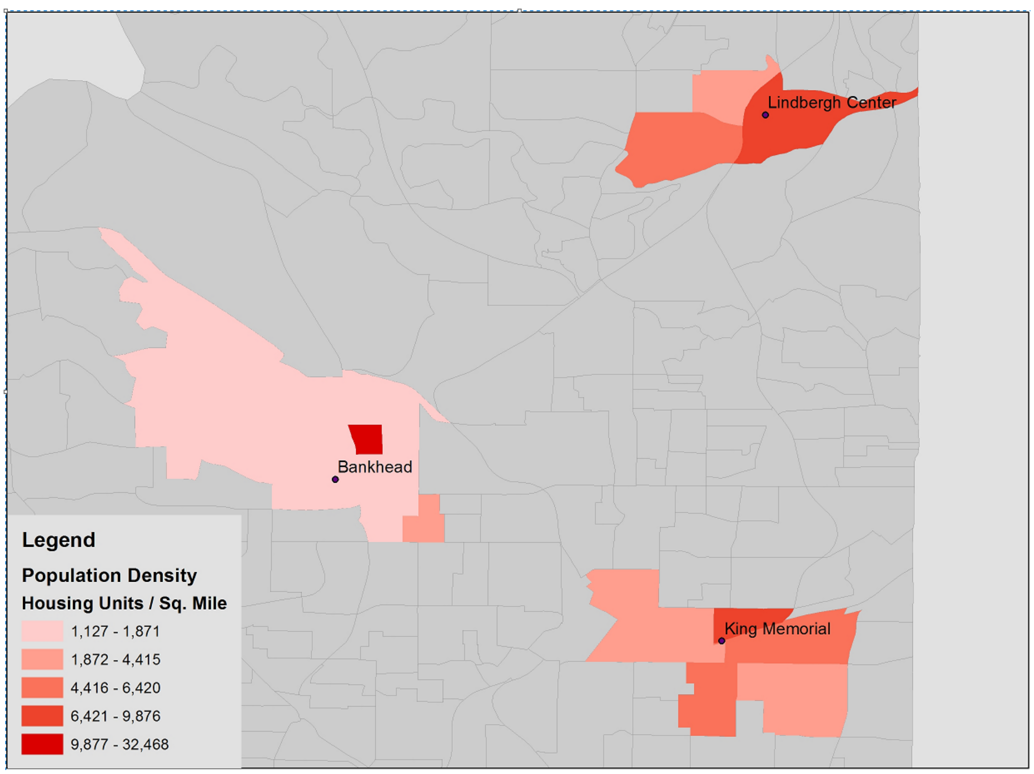

Figure 5 – Population Density - 3 neighborhoods.

The median household income in areas surrounding the Lindbergh Center Station is higher than the two other study areas (Bankhead and King Memorial). However, the two other stations have almost similar median household income. The south areas of the King Memorial station have a higher median income compare with the Bankhead station.

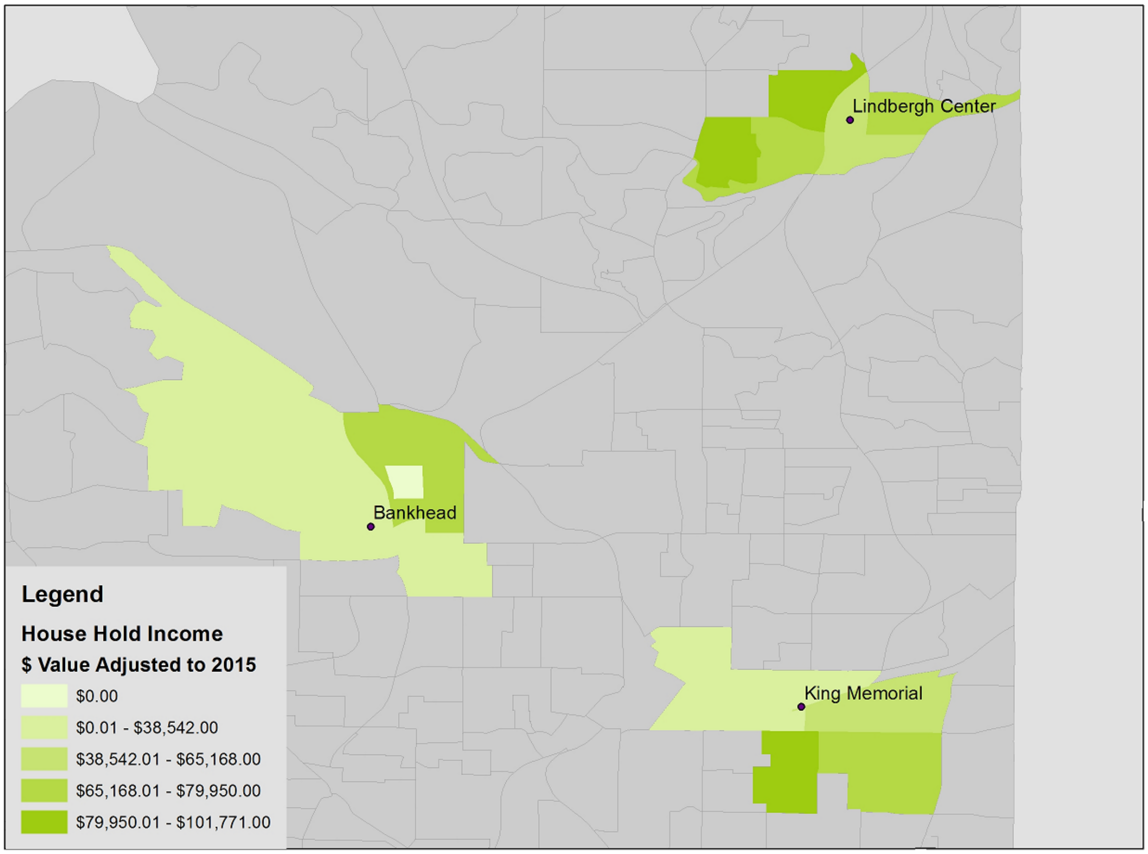

Figure 6 – Median Household Income ($ value adjusted to 2015): 3 stations.

The high employment rate at the two neighborhoods surrounding the Lindbergh Center and King Memorial stations makes them a good candidate for reducing the energy consumption resulting from the implementation of TOD.

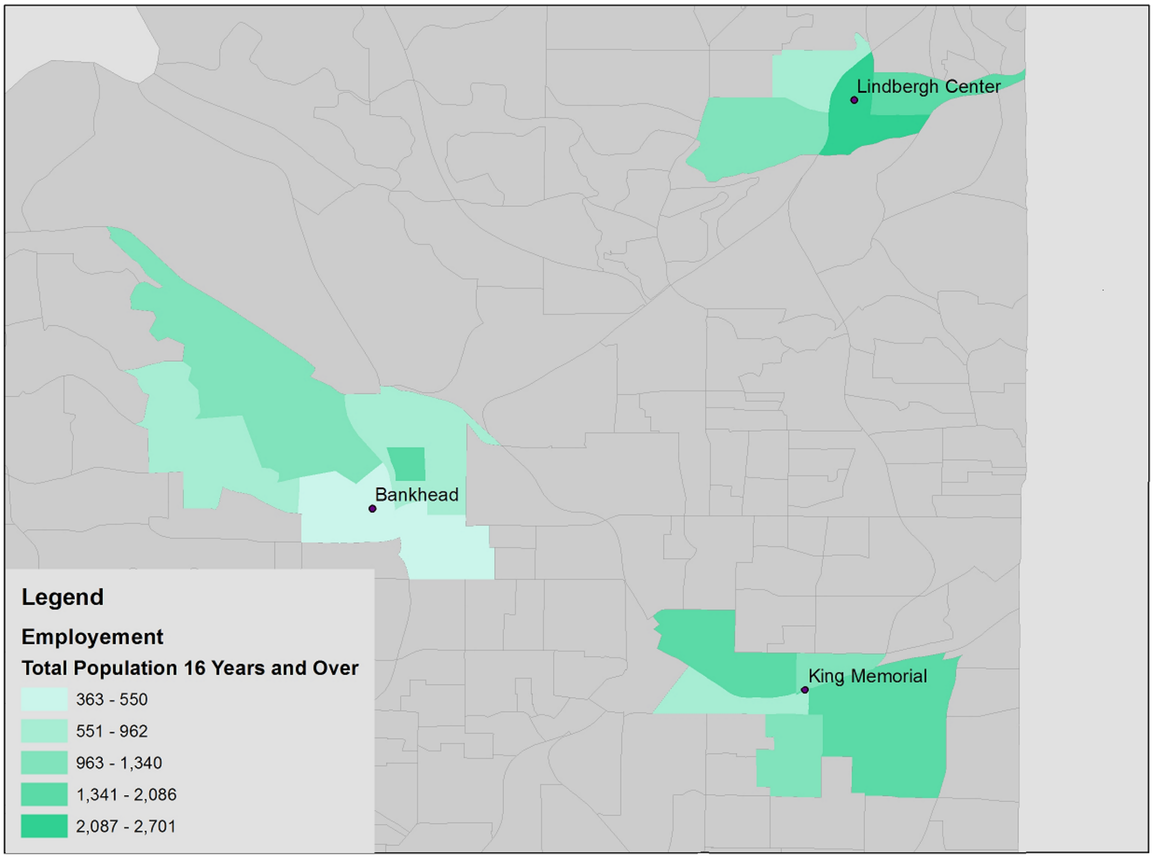

Figure 7 – Employment Condition (19 yr.old and higher): 3 stations

The next chapter, presents the result of energy consumption calculation before and after the implementation of MXD plan in the three study areas surrounding the three MARTA stations.

CHAPTER 5. STUDY RESULT

The result of aggregated daily VMT calculation shows the Lindbergh Center station has the highest VMT among the three stations. However, number of Households living in areas surrounding the Lindbergh Center station is also the highest among the three stations. Normalization of the VMT based on the number of households shows the Bankhead station has the highest VMT per HH per day. Considering the MPG 20.1 for combustion engine (including hybrid cars) and 4 Miles / KWh for the Electric Vehicles, the energy consumption in the transportation sector is calculated for each of the three study areas.

Table 3 – VMT across the Three Transit Stations.

	Lindbergh Center Station	King Memorial Station	Bankhead Station
VMT	79,846	54,506	43,371
# of HH	3,311	3,198	1,318
VMT/HH	24.11	17.043	32.9

Table 4 – Energy Consumption – Transportation Sector.

	Lindbergh Center Station	King Memorial Station	Bankhead Station
100% combustion engine (Gal. Gasoline/day)	3,972	2,711	2,157
100% EVs (KWh /day)	19,961	13,626	10,842

The focus of this study is examining the change in energy consumption after the implementation of the TOD plan. The result of the VMT calculation is used to calculate the total energy consumption in the transportation sector, before the TOD, as the benchmark. The result of the energy calculation shows the Lindbergh Center and King Memorial Stations consume the highest energy in the residential sector. Considering the total number of the Households to normalize the result, the result of energy consumption in all three stations is summarized in Table 5.

Table 5 – Energy Consumption – Residential sector - Three Transit Stations.

	Lindbergh Center Station	King Memorial Station	Bankhead Station
KWh / Yr.	51,208,057	41,974,475	20,435,422
# of HH	3,311	3,198	1,318
KWh/HH per Yr.	15,466	13,125	15,504

In the next step, in this study I used the MXD toolset developed by EPA to examine the impact of the TOD on VMT reduction. At the same time, due to the increase in population density in the study are, the energy consumption in the residential sector will increase. In this study, I assume the energy consumption per household in the residential sector holds the same rate before and after the implementation of TOD and the total energy consumption change in the residential sector is calculated based on the increase in the number of households due to the increase in the population density. **Table 6** summarizes the result of the VMT reduction in the three stations, after the implementation of the TOD plan. The summary of energy consumption change in the transportation and residential sectors after the implementation of the TOD is presented in Table 7.

Table 6 – VMT change due to the implementation of TOD plan: Three study areas.

Study Area	VMT Reduction	VMT before MXD	VMT after MXD
Bankhead Station	4%	43,371	41,636
King Memorial Station	7%	54,506	50,690
Lindbergh Center Station	4%	79,846	76,646

Based on the results from the MXD toolset in each three station, the amount of energy consumption reduction is calculated for the transportation sector. Despite the reduction of energy consumption in the transportation sector, the MXD can result in an increase in energy consumption of buildings, due to the increase in density, and the added commercial and business units within the development areas. Such an increase occurs at the aggregated level, while the at residential sector may not increase significantly as the aim of the transportation oriented development is to provide a pedestrian friendly environment in a mixed used developed neighborhood, where the residents can easily replace the car with walking mode, for many of their day to day trips. As the result, the energy consumption reduction is calculated based on the reduction in VMT after the implementation of MXD. Table 7 summarizes the result of the reduction in energy consumption for the three neighborhoods.

Table 7 – Energy Consumption change due to the implementation of TOD plan: three study areas.

Study Area	Transportation sector	
	VMT reduction (Miles / Day)	Energy Consumption reduction (KWh / Day)
Bankhead Station	1,734.8	2,914.4
King Memorial Station	3,815.4	6,409.8
Lindbergh Center Station	3,193.8	5,365.5

The result of the calculation shows the King Memorial station has the highest potential to reduce the energy consumption by implementing the TOD. Despite the high density and high VMT in the area surrounding the King Memorial station, the presence of retails, shops, restaurants and office buildings increase the potential decrease in VMT after the TOD implementation. Areas surrounding the Lindbergh Center station may not have the experience the high reduction rate in VMT after the implementation of TOD, but due to the high VMT value, the VMT reduction in this area is almost as high as the areas surrounding the King Memorial station. Bankhead station has the lowest VMT and lowest reduction rate, which makes it less desirable for the TOD plan. However, considering the residents in neighborhoods surrounding the Bankhead station are belong to the low-income class, the TOD plan for this area can improve the equity and mobility and improves the public safety. To normalize the result, I use the number of households in each study area. Table 8 summarizes the result of the calculation of the energy consumption per household.

Table 8 – Energy Consumption – per household per year: before and after TOD implementation.

	Energy Consumption (KWh per HH per year)	
Study Area	Before the TOD implementation	After the TOD implementation
Bankhead Station	97.47	95.27
King Memorial Station	64.43	62.43
Lindbergh Center Station	82.76	81.37

The result of this study shows the TOD plan can reduce the energy consumption per household, in the cities. There are many factors influencing the energy consumption reduction, which require to be considered by planners and policy makers to maximize the benefit of TOD.

CHAPTER 6. CONCLUSION

In the US, the transportation and residential sectors consume more than half of the total end-use energy consumption (EIA 2009). The growth of the population and urbanization in the US makes the cities highly dependent to energy sources for their sustainable future growth. Examining the energy consumption in urban areas is a required element for planning in the future development. This study demonstrates a possible method for calculating the energy consumption at the neighborhood level for the two end-use sectors residential and transportation sector. The proposed energy consumption calculation is on both physical and behavioral characteristics of the resident in each neighborhood. The energy consumption at neighborhood level is then calculated for the three neighborhoods in the Atlanta Metropolitan area, each surrounding one transit stop. Each neighborhood is selected based on the socio-economic characteristics of their residents, where the three neighborhoods cover the three socio-economic levels, previously defined in another study in the Atlanta. Furthermore, this study examines the implementation of the MXD in three pre-selected neighborhoods. The MXD as a TOD strategy can reduce the energy consumption in neighborhood by providing a pedestrian friendly for the residents with mixed-used and dense development that reduce their need to use the cars for a part of their daily commute needs. Moreover, the existence of a transit stop within a walking distance can provide a replacement for the cars with the transit system, for the daily transportation demand in the neighborhood with the TOD. This study shows the TOD is a promising development strategy for reducing the energy consumption in the neighborhoods per capita. There is still room for the future studies in the similar field. This study did not cover the energy consumption in the commercial sector. Also, the energy consumption in transit system is not calculated in this study. The method is used in this study to calculate the energy consumption at residential sector is one of the approved methods that can be used to calculate the energy consumption in the residential sector. The accuracy of the regression method ties with the number of independent variables with no collinearity in the regression. If additional information be available, the future studies can improve the accuracy of the energy consumption calculation by adding those variable as independent variables in the regression. However, the current result of the energy consumption is within the boundary of energy consumption of households in the Atlanta, GA. The reduction in energy consumption, due to the TOD shows a promising solution for the future development in urban areas in the US. Urban areas are the source of the majority of the energy consumption and the concept of “low carbon cities”, with the goal of reduction in environmental impact of current energy consumption in cities, can be gained by implementing strategies to reduce the energy consumption in addition to the use of renewable energy sources.

REFERENCES

Abu Bakar, & Cheen. (2013). A Framework for Assessing the Sustainable Urban Development. Procedia - Social and Behavioral Sciences, 85, 484-492.

Ali-Toudert, F., and H. Mayer. (2006). Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. Building and Environment 41(2):94–108.

Arnfield, A. J. (1990). Street design and urban canyon solar access. Energy and Buildings 14 (2):117–131.

Arboit, Mesa, Diblasi, Fernández Llano, & De Rosa. (2010). Assessing the solar potential of low-density urban environments in Andean cities with desert climates: The case of the city of Mendoza, in Argentina. 2nd. Part. Renewable Energy, 35(7), 1551-1558.

Breheny, M. (1995) Counterurbanisation and sustainable urban forms. In: Brotchie, J.; Batty, M.; Blakely, E.; Hall, P. and Newton, P. (eds.). Cities in Competition. Productive and sustainable cities for the 21st century. Longman Australia Pty Ltd., Melbourne. pp. 402-429

Brown, M. (2009). Growing Cooler: The Evidence on Urban Development and Climate Change – By Reid Ewing, Keith Bartholomew, Steve Winkelman, Jerry Walters, and Don Chen. Review of Policy Research, 26(1-2), 228-231.

Cervero, and Kockelman. "Travel Demand and the 3Ds: Density, Diversity, and Design." Transportation Research Part D 2, no. 3 (1997): 199-219.

Cervero, R. (1989) Jobs-housing balancing and regional mobility. Journal of the American Planning Association , Vol. 55, No. 2, pp. 136-150

Cervero R. and J Murakami. (2010). Effects of built environments on vehicle miles traveled evidence from 370 US urbanized areas. Environment and Planning A 42:400-418.

Correia Guedes, Pinheiro, & Manuel Alves. (2009). Sustainable architecture and urban design in Portugal: An overview. Renewable Energy, 34(9), 1999-2006.

Chatman D G. (2008). Deconstructing development density: Quality, quantity and price effects on household non-work travel. Transportation Research Part A: Policy and Practice 42 (7):1008-1030.

Cheng, V., K. Steemers, M. Montavon, and R. Compagnon. 2006. Urban form, density and solar potential. Paper presented at the 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, September6–8.

Dimitrova, Elena. "The ‘sustainable Development’ Concept in Urban Planning Education: Lessons Learned on a Bulgarian Path." Journal of Cleaner Production 62 (2014): 120-27.

Energy Information Administration. 2011. Annual Energy Review 2011. Retrieved from

http://www.eia.doe.gov/emeu/aer/consump.html (Access Dec. 2016).

EIA - World Energy Outlook 2015. Energy Information Administration (EIA), Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC; 2011.

Echenique, M., Hargreaves, A., Mitchell, G., & Namdeo, A. (2012). Growing Cities Sustainably: Does Urban Form Really Matter? American Planning Association. Journal of the American Planning Association, 78(2), 121.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment. Journal of the American Planning Association, 76(3), 265-294.

Ewing, R., & Cervero, R. (2001). Travel and the built environment: a synthesis. Transportation Research Record: Journal of the Transportation Research Board, 1780: 87–1.

Ewing, R. and R. Cervero. 2010. Travel and the built environment. Journal of the American Planning Association 76 (3): 265–294.

Ewing, R., and F. Rong. 2008. The impact of urban form on US residential energy use. Housing Policy Debate 19 (1): 1–30.

Ewing, R., and F. Rong. (2008). The impact of urban form on US residential energy use. Housing Policy Debate 19 (1): 1–30

Givoni, B. (1998).Climate Considerations in Building and Urban Design. New York: Wiley & Sons. Cheng, V., K. Steemers, M. Montavon, and R. Compagnon. 2006. Urban form, density and solar potential. Paper presented at the 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, September6–8.

Hough, M. (1995). Cities and Natural Process. London and New York: Routledge

Gadsden, Rylatt, & Lomas. (2003). Putting solar energy on the urban map: A new GIS-based approach for dwellings. Solar Energy, 74(5), 397-407.

Hawkes, D. (1995). Towards the sustainable city. Renewable Energy, 6(3), 345-352.

Hofierka, & Kaňuk. (2009). Assessment of photovoltaic potential in urban areas using open-source solar radiation tools. Renewable Energy, 34(10), 2206-2214.

Holden, E., and I. T. Norland. 2005. Three challenges for the compact city as a sustainable urban form: household consumption of energy and transport in eight residential areas in the greater Oslo region. Urban Studies 42 (12): 2145– 2166.

Hough, M. 1995. Cities and Natural Process. London and New York: Routledge.

Hirst, ., R. Goeltz, and J. Carney. 1982. Residential energy use : Analysis of disaggregate data. Energy Economics 4 (2): 74–82.

Holtzclaw J, R Clear, H Dittmar, D Goldstein and P Haas. (2002). Location efficiency: neighborhood and socio-economic characteristics determine auto ownership and use – studies in Chicago, Los Angeles and San Francisco. Transportation Planning and Technology 25 (1): 1–27.

Kaza, N., & Curtis, M. (2014). The Land Use Energy Connection. Journal of Planning Literature, 29(4), 355-369.

Kaza N and M P Curtis. 2014. The Land Use Energy Connection. Journal of Planning Literature 29 (4): 355-369. doi:10.1177/0885412214542049

Ko, Ye, Radke, John D., Arens, Edward, and Mozingo, Louise. The Energy Impact of Urban Form: An Approach to Morphologically Evaluating the Energy Performance of Neighborhoods, 2012, ProQuest Dissertations and Theses.

Levinson, R., Akbari, H., & Pomerantz, M. (2010). Solar access of residential rooftops in four California cities. Solar Energy, Solar Energy, 2010.

Meldem, R., and F. Winkelmann. (1998). Comparison of DOE-2 with temperature measurements in the Pala test houses. Energy and Buildings 27 (1):69–81.

Mitchell, G. 2005. Urban development, form and energy use in buildings: A review for the SOLUTIONS project. School of Geography and Institute for Transport Studies, University of Leeds. Retrieved from www.suburbansolutions.ac.uk/DocumentManager/secure0/Urban development, form and energy use in buildings.pdf. (Access Dec. 2016).

Mindali, Raveh, and Salomon. "Urban Density and Energy Consumption: A New Look at Old Statistics." Transportation Research Part A 38, no. 2 (2004): 143-62.

Marshall, Julian D. "Energy-efficient Urban Form." Environmental Science & Technology 42, no. 9 (2008): 3133-7.

Newman P.W.G. and Kenworthy, J.R. (1989). Cities and automobile dependence. An international sourcebook. Gower Technical, Aldershot.

Naess, P. and Sandberg, S.L. (1996) Workplace location, modal split and energy use forcommuting trips. Urban Studies, Vol. 33, No. 3, pp. 557-580.

Nguyen, H., & Pearce, J. (2010). Estimating potential photovoltaic yield with r.sun and the open source Geographical Resources Analysis Support System. Solar Energy, 84(5), Solar Energy, 2010, Vol.84(5).

Owens, S. E. 1986. Energy, Planning, and Urban Form. London: Pion Ltd.

Parsons Brinckerhoff Quade and Douglas, Inc. (1994). Building orientation - A supplement to the pedestrian environment Portland: 1000 friends of Oregon http://ntl.bts.gov/DOCS/bob.html.

Pickrell, D.,and P. Schimek.1999. Growth in motor vehicle ownership and use: Evidence from the Nationwide Personal Transportation Survey. Journal of Transportation and Statistics 2(1), 1–17.

Randolph, J. 2008. Comment on Reid Ewing and Fang Rong's‘ the impact of urban form on U.S. residential energy use'. Housing Policy Debate 19(1): 45–52.

Rai, V., & Sigrin, B. (2013). Diffusion of environmentally-friendly energy technologies: Buy versus lease differences in residential PV markets. Environmental Research Letters, 8(1), 8.

Ratti, Baker, and Steemers. "Energy Consumption and Urban Texture." Energy & Buildings 37, no. 7 (2005): 762-76.

Rosales, N. (2011). Towards the Modeling of Sustainability into Urban Planning: Using Indicators to Build Sustainable Cities. Procedia Engineering, 21, 641-647.

Rylatt, M., Gadsden, S., & Lomas, K. (2003). Using GIS to estimate the replacement potential of solar energy for urban dwellings. Environment and Planning B: Planning and Design, 30(1), 51-68.

SEIA, (2016). Solar Spotlight: Georgia. Solar Energy Industries Association. (Access Nov 2016) www.seia.org/sites/default/files/GA%20State%20Fact%20Sheet_9.9.2016.pdf

Staley, S. R. 2008. Missing the forest through the trees? Comment on Reid Ewing and Fang Rong's the impact of urban form on U.S. residential energy use'. Housing Policy Debate 19 (1): 31–43.

Stead, D. (1999) Planning for less travel – identifying land use characteristics associated with more sustainable travel patterns Unpublished PhD Thesis, Bartlett School of Planning, University College London, London.

Steemers, K. 2003. Energy and the city: density, buildings and transport. Energy and Buildings35 (1): 3–14

Tahmasebi, Banihashemi, and Hassanabadi. "Assessment of the Variation Impacts of Window on Energy Consumption and Carbon Footprint." Procedia Engineering 21 (2011): 820-28.

Vardimon, R. (2011). Assessment of the potential for distributed photovoltaic electricity production in Israel. Renewable Energy, 36(2), 591-594.

Wiginton, Nguyen, & Pearce. (2010). Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. Computers, Environment and Urban Systems, 34(4), 345-357.

Zhou B B and K M Kockelman. (2008). Self-selection in home choice: use of treatment effects in evaluating relationship between built environment and travel behavior. Transportation Research Record: Journal of the Transportation Research Board 2077: 54–61.

"Annual Energy Review - Energy Information Administration." Accessed April 5, 2017. https://www.eia.gov/totalenergy/data/annual/#consumption.

"APTA Q4 2015 Ridership Report - 2015-q4-Ridership-APTA.pdf." Accessed April 15, 2017. http://www.apta.com/resources/statistics/Documents/Ridership/2015-q4-ridership-APTA.pdf.

Banister, D, S Watson, and C Wood. "Sustainable Cities: Transport, Energy, and Urban Form." *Environment and Planning B: Planning and Design* 24, no. 1 (February 1, 1997): 125–43. doi:10.1068/b240125.

Brownstone, David, and Thomas F. Golob. "The Impact of Residential Density on Vehicle Usage and Energy Consumption." *Journal of Urban Economics* 65, no. 1 (January 2009): 91–98. doi:10.1016/j.jue.2008.09.002.

Bureau, US Census. "ACS Information Guide." Accessed April 15, 2017. https://www.census.gov/programs-surveys/acs/about/information-guide.html.

Cervero, Robert. "Transit-Oriented Development's Ridership Bonus: A Product of Self-Selection and Public Policies." *Environment and Planning A* 39, no. 9 (September 1, 2007): 2068–85. doi:10.1068/a38377.

Cervero, Robert, and Cathleen Sullivan. "Green TODs: Marrying Transit-Oriented Development and Green Urbanism." *International Journal of Sustainable Development & World Ecology* 18, no. 3 (June 1, 2011): 210–18. doi:10.1080/13504509.2011.570801.

"coUrbanize - MARTA." Accessed April 15, 2017. https://courbanize.com/projects/marta.

De Vos, Jonas, Veronique Van Acker, and Frank Witlox. "The Influence of Attitudes on Transit-Oriented Development: An Explorative Analysis." *Transport Policy* 35 (September 2014): 326–29. doi:10.1016/j.tranpol.2014.04.004.

Gulden, Jeff, J. Goates, and Reid Ewing. “Mixed-Use Development Trip Generation Model.” *Transportation Research Record: Journal of the Transportation Research Board* 2344 (November 1, 2013): 98–106. doi:10.3141/2344-11.

Heiple, Shem, and David J. Sailor. “Using Building Energy Simulation and Geospatial Modeling Techniques to Determine High Resolution Building Sector Energy Consumption Profiles.” *Energy and Buildings* 40, no. 8 (2008): 1426–36. doi:10.1016/j.enbuild.2008.01.005.

“Impact of Anthropogenic Heat on Urban Climate in Tokyo.” Accessed April 8, 2017. http://www.sciencedirect.com/science/article/pii/S1352231099001326.

“Impacts of City-Block-Scale Countermeasures against Urban Heat-Island Phenomena upon a Building’s Energy-Consumption for Air-Conditioning.” Accessed April 8, 2017. http://www.sciencedirect.com/science/article/pii/S0306261905000711.

Jared Rodriguez. “Special Section: Perspectives on Sprawl Development and Growth.” *Leadership and Management in Engineering* 13, no. 3 (July 1, 2013): 121–22. doi:10.1061/(ASCE)LM.1943-5630.0000232.

“Learning About Renewable Energy | NREL.” Accessed April 5, 2017. https://www.nrel.gov/workingwithus/learning.html.

Lutzenhiser, Loren. “A Cultural Model of Household Energy Consumption.” *Energy* 17, no. 1 (January 1992): 47–60. doi:10.1016/0360-5442(92)90032-U.

“MARTA.” Accessed April 15, 2017. http://www.itsmarta.com/MARTA-at-a-Glance.aspx.

“MARTA.” Accessed April 15, 2017. http://www.itsmarta.com/tod-overview.aspx.

“Modeling.” Accessed April 8, 2017. http://www.atlantaregional.com/transportation/modeling.

National Academies of Sciences, Engineering. *Effects of TOD on Housing, Parking, and Travel*, 2008. https://www.nap.edu/catalog/14179/effects-of-tod-on-housing-parking-and-travel.

“NQOLH SEC Index.” Accessed April 15, 2017. https://cgis.gatech.edu/NQOLH/SEC_Index/.

O’Neill, Brian C., and Belinda S. Chen. “Demographic Determinants of Household Energy Use in the United States.” *Population and Development Review* 28 (2002): 53–88.

“P38602 Lindbergh Center Station - Phase II TOD Master Plan.pdf.” Accessed April 15, 2017. https://www.itsmarta.com/uploadedFiles/More/Transit_Oriented_Development/P

38602%20Lindbergh%20Center%20Station%20-%20Phase%20II%20TOD%20Master%20Plan.pdf.

Polzin, Steven, Xuehao Chu, and Lavenia Toole-Holt. “Forecasts of Future Vehicle Miles of Travel in the United States.” *Transportation Research Record: Journal of the Transportation Research Board* 1895 (January 1, 2004): 147–55. doi:10.3141/1895-19.

“Publication: World Energy Outlook 2016 - Excerpt - Water-Energy Nexus.” Accessed April 5, 2017. http://www.iea.org/publications/freepublications/publication/world-energy-outlook-2016---excerpt---water-energy-nexus.html.

Ratner, Keith A., and Andrew R. Goetz. “The Reshaping of Land Use and Urban Form in Denver through Transit-Oriented Development.” *Cities*, Special Section: Analysis and Planning of Urban Settlements: The Role of Accessibility, 30 (February 2013): 31–46. doi:10.1016/j.cities.2012.08.007.

Rentziou, Aikaterini, Konstantina Gkritza, and Reginald R. Souleyrette. “VMT, Energy Consumption, and GHG Emissions Forecasting for Passenger Transportation.” *Transportation Research Part A: Policy and Practice* 46, no. 3 (March 2012): 487–500. doi:10.1016/j.tra.2011.11.009.

“Residential Energy Consumption Survey (RECS) - Data - U.S. Energy Information Administration (EIA).” Accessed April 15, 2017. https://www.eia.gov/consumption/residential/data/2009/index.php?view=microdata.

Sailor, David J., and Lu Lu. “A Top-down Methodology for Developing Diurnal and Seasonal Anthropogenic Heating Profiles for Urban Areas.” *Atmospheric Environment* 38 (2004): 2737–48. doi:10.1016/j.atmosenv.2004.01.034.

“Statistical Review of World Energy | Energy Economics | BP Global.” *Bp.com*. Accessed April 5, 2017. http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

Swan, Lukas G., and V. Ismet Ugursal. “Modeling of End-Use Energy Consumption in the Residential Sector: A Review of Modeling Techniques.” *Renewable and Sustainable Energy Reviews* 13, no. 8 (October 2009): 1819–35. doi:10.1016/j.rser.2008.09.033.

“Transit and Job Accessibility: An Empirical Study of Access to Competitive Clusters and Regional Growth Strategies for Enhancing Transit Accessibility.” Accessed April 8, 2017. http://www.sciencedirect.com/science/article/pii/S0967070X1400033X.

“Transit Oriented Development | Atlanta Regional Commission.” Accessed April 7, 2017. http://www.atlantaregional.com/land-use/transit-oriented-development.

"Transportation Access and Mobility | Atlanta Regional Commission." Accessed April 8, 2017. http://www.atlantaregional.com/transportation/overview.

"Travel Characteristics of Transit-Oriented Development in California." *Community-Wealth.org*, June 25, 2012. http://community-wealth.org/content/travel-characteristics-transit-oriented-development-california.

Williams, Katie, and Michael Jenks. *Achieving Sustainable Urban Form*. Taylor & Francis, 2000.

Cervero, Robert. 2004. "Transit-oriented development in the United States: experiences, challenges, and prospects". *Transportation Research Board of the National Academies*, Washington, D.C. c2004.

FTA (Federal Transit Administration). 2000. "Transit Benefits, Working Papers: A Public Choice Policy Analysis". Washington, D.C.: Federal Transit Administration, Office of Policy Development.